illness, dealt with the shift of the western shore-line in England and Wales during the Avonian period. He concluded that a land mass stretching from Wales to Wicklow formed a barrier during the Avonian period between a "N.W. channel," reaching to the Isle of Man and the Lake district, and a "S.W. channel," which was an extended Bristol Channel. This barrier formed the land-crest between these two channels during the whole of Viséan time, and had a dominant trend from Anglesey to Dudley. The whole neck of land which contained the barrier and separated the "channels" shifted steadily southwards as Viséan time proceeded, owing to the advance of the sea on its northern side and its retreat on the south. The remarkable similarity of the Viséan sequence north and south of this barrier indicated free sea communication round its western margin, along which the sea remained persistently coastal during the period.

Dr. Albert Jowett contributed a preliminary note on the glaciation of the western slopes of the southern Pennines. No striated surfaces of solid rock had been found at high levels, and for detailed information of the ice-movement we had to depend on striations at Salford and Fallowfield, on the distribution of drift at high levels, and on the systems of drainage along the edge of the ice. These indicated a general movement from N.W.–S.E. The first barrier of hills met with on approaching the Pennines from the South Lancashire and Cheshire plain was almost everywhere overridden with ice, which left definite deposits of drift with foreign rocks up to 1360 ft., and scattered erratics up to 1400 ft. This drift had been traced across the main Pennine divide near Chapel-le-Frith (1100 ft.). Great lakes were held up by the ice-barrier some time after it commenced to retreat from the western slope of the Pennines. During early stages of the retreat the drainage from the lakes in and north of the Etherow valley escaped northwards, and ultimately discharged through the Walsden gap into the Calder. When the ice-barrier east of Manchester fell below 600 ft., this drainage followed the course of that south of the Etherow valley and escaped southwards.

The afternoon meeting commenced with a discussion on radio-active problems in geology. Sir E. Rutherford opened the discussion by putting the problem from the point of view of the older geologists, with their comparatively low estimate of the age of the earth, though higher than physicists of those days were inclined to concede. The discovery of radium had greatly modified the position, and the age of the earth, based on evidence of radio-activity, was very much higher than the estimates accepted by geologists. The problem was how to reconcile geological facts with these new physical determinations. Sir Ernest Rutherford was inclined to believe that the larger estimates were nearer correct than the smaller.

Prof. J. Joly faced the problem from the viewpoint of the geologist on the assumption that geologists were agreed on the matter. He made several suggestions which might have the effect of reducing the large numbers derived from the study of radio-active materials.

Prof. Soddy hoped that geologists would not be in any immediate hurry to decide between the geological and radio-active estimates of the age of the earth. Owing to the element of uncertainty about the initial stages of the disintegration and the long periods involved, there was a great *terra incognita,* and the new theory of isotopes made it necessary to take into account many possibilities not thought of a couple of years ago. In addition there was always the possibility that thorium might be a branch of the uranium family, in which case some of the arguments that had been used entirely fell to the ground. While he saw no successful method at present of altering the *general* order of the radio-active estimate, he did not regard it as more than tentative, and there might well be unknown factors of sufficient importance to bring the two methods into closer agreement in the future. Dr. J. H. Teall, Prof. Sollas, and Dr. J. W. Evans continued the discussion.

Prof. C. A. Edwards described the results of experiments producing twinning in metallic crystals. His remarks were illustrated by an interesting series of lantern slides. Dr. J. W. Evans followed with a description of the different methods by which the interference figures of a small mineral in a rock slice could be kept distinct from those of the adjoining minerals. He discussed various methods of using a diaphragm with the Becke combination of lenses, and condemned the common practice of placing the diaphragm for this purpose immediately below the Bertrand lens.

Dr. G. Hickling contributed a paper on the microstructure of coal, illustrated by a series of beautiful lantern slides, showing remarkable success in dealing with very difficult material. He concluded that coal was essentially a "replacement" deposit consisting of an original peat-like mass of vegetable *débris,* in which the substance of the component tissues has been largely or wholly replaced by the liquid decomposition products of other vegetation. The concluding paper was by Mr. Thomas Crook, describing the economic mineral products of Damaraland, S.W. Africa, and emphasising their value. Several research committees were reappointed; and new committees were appointed to investigate rocks of Old Red Sandstone age at Rhynie, Aberdeenshire, and of Lower Carboniferous age at Gullane, Haddingtonshire. The sectional work concluded with a field excursion to Edale and Castleton. The surprise of the week was the magnificent weather, which made a successful meeting also a delightful memory.

W. L. C.

CORRESPONDING SOCIETIES AT THE BRITISH ASSOCIATION.

THE first meeting of the Conference of Delegates was held on September 8, and it was announced that the General Committee of the British Association had altered the titles of officers of the Conference from Chairman and Vice-Chairman to President and Vice-President, thereby giving them the same status as those of the Sections. Sir Thomas Holland delivered his opening address, entitled "The Classification of Scientific Societies," which was printed in NATURE of September 16.

The first subject for discussion was "Local Museums," suggested by the Selborne Society, and introduced by Dr. W. E. Hoyle. He laid it down that the first and fundamental function of a museum was to preserve. Museum officials are nowadays given so much advice about the desirability of making our exhibits æsthetically attractive, of compiling explanatory labels which shall at the same time instruct the specialist and interest the casual visitor, and of catering for school children, that they are, he said, in danger, perhaps, of forgetting that their paramount duty is to see that "neither moth nor rust doth corrupt" and that "thieves do not break through nor steal."

He gave a definition of a local museum, the first duty of which, he maintained, was to preserve the things of interest pertaining to the locality. Then he touched upon the important and delicate question of the relations which ought to exist between the local museum and the national museum. Difficulties arose when it was required to determine in particular cases what objects were of national importance and should be preserved in a national museum.

After the first function of a local museum had been adequately discharged, Dr. Hoyle thought that if means and opportunities allowed, collections should be provided which gave the visitor a preliminary sketch of some department of knowledge. He alluded to "index" collections, though he thought the term "introductory" collections would be more appropriate. Dr. Hoyle had something to say with regard to the coming into touch of the museum with the educational system of the locality, and he saw nothing out of place in a local museum developing a special subject quite disconnected with the locality if it had the power to do so without interfering with its proper work.

In the discussion which followed, Dr. Bather touched upon principles which should guide local curators in their selection of what should be considered of national and local interest. Type specimens should be placed in museums where they would be well looked after. Moreover, researchers, though they would naturally seek for local objects, such as fossils, in a local museum, ought not to have to look for, say, New Zealand fossils, through all the museums of the British Isles.

Dr. Marie C. Stopes thought that there might be a balance of good in decentralising collections, even of type specimens, for the visiting of local museums brings a stimulus to the local people, and widens and humanises the interests of specialists.

It seemed evident from other remarks that if local museums are to be properly educational, in the general sense of the word, there should be special institutions or special sections of existing museums with their own organisation, so as not to burden curators unduly.

Prof. Geddes directed attention to the survey of Greater London now being carried out by the Architects' War Committee, which deserved the co-operation of museums and natural history societies.

The second meeting was held on Friday, September 10. As a result of the importance of the presidential address, and the interest which had been taken in its suggestions, the vice-president, Mr. William Whitaker, moved a resolution in the following terms:—"That this conference invites the attention of the Corresponding Societies' Committee to the president's opening address, in which suggestions are made for reforming the existing, varied, and unorganised practice of publishing original papers." An outline was given of ways in which this might be done, and the resolution was carried.

The second subject for discussion was "Colour Standards," suggested by the British Mycological Society, and introduced by Mr. J. Ramsbottom. He described and illustrated a number of the schemes which had been formulated with the object of obtaining some uniformity of colour description in the many branches of natural science. Recent attempts at colour standards have each something against their general adoption, and, except for horticulturists, mycologists, and possibly ornithologists, they are much too full. It would seem best to have a well-arranged list of two hundred well-named colours for ordinary use, which colour scheme could be amplified in those branches of science where needed.

In this case, also, a good discussion was aroused, and as it was pointed out that the work of preparing such a series of colour standards for scientific and commercial uses, though of interest to many of the committees of the Association, was not the province of any one of them, a resolution was passed referring the matter to the Corresponding Societies' Committee.

In many ways the Conference of Delegates at Manchester was the most successful that had been held in this country for a considerable time.

WILFRED MARK WEBB.

SECTION B.

CHEMISTRY.

OPENING ADDRESS[1] BY PROF. WILLIAM A. BONE, D.SC., F.R.S., PRESIDENT OF THE SECTION.

THIS year is, as many of you are doubtless aware, the centenary of Davy's invention of the miner's safety lamp which formed the starting point of his brilliant researches upon flame, in which he disclosed, and brought within the range of experimental inquiry, most of the intricate and baffling problems connected with the fascinating subject of gaseous combustion. Also the ground on which we meet to-day is known to the whole scientific world as the place where, during more than a quarter of a century of continuous investigation, a succession of Manchester chemists, led and inspired by Prof. H. B. Dixon, have devoted themselves to the elucidation of the many problems which Davy's work foreshadowed. Therefore, both in point of time and place, the occasion is singularly appropriate for a review of recent advances in this important field of scientific inquiry.

At the Sheffield meeting of the Association in 1910, I had the honour of presenting to a joint conference of Sections A and B (Physics and Chemistry) a report summarising the then "State of Science in Gaseous Combustion,"[2] which gave rise to a keen and stimulating discussion, and was not only printed *in extenso* in the annual reports for that year, but was also widely circulated through the medium of the scientific and technical Press. There is no need, therefore, for me to refer in any detail to the results of researches already dealt with in that report. I can more usefully devote part of the time at my disposal to supplementing it with a review of more recent researches, which have considerably extended our knowledge in many directions.

Gaseous Combustion: Ignition Phenomena.

The first section of my 1910 report was concerned with ignition temperatures and the initial phases of gaseous explosions; and it is in connection with ignition phenomena that subsequent progress has been most marked.

For the ignition of a given explosive mixture, it is necessary that the temperature of its constituents should be raised, at least locally, to a degree at which a mass of gas self-heats itself by combination until it bursts into flame, or, in other words, to a degree at which the chemical action becomes autogenous or self-propelling, so that it quickly spreads throughout the whole mass. This particular degree, or in some cases range, of temperature is commonly spoken of as the ignition-point of the mixture; but in using the expression, certain qualifications should be carefully borne in mind In the first place, as H. B. Dixon and H. F. Coward showed in 1909,[3] whereas when certain combustible gases—such, for example, as hydrogen and carbon monoxide, the mechanism of the combustion of which is probably of a fairly simple character—and air or oxygen are separately heated in a suitable enclosure before being allowed to mix, the temperature at which ignition occurs lies within a very narrow range, which is, within the limits of experimental error, the same for both air and oxygen (*i.e.* in the case of hydrogen it is 580° to 590°, and for carbon monoxide 640° to 658°). On the other hand, in cases where the mechanism of combustion is known to be very complex (*i.e.* hydrocarbons), the ignition range is either fairly wide or else is materially lower in oxygen than in air (or both). Thus—

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[1] Abridged by the author.

[2] See *Journal of Gas Lighting*, vol. cxi., p. 648.

[3] *Ibid.*, vol. cvii., p. 323.

	In air	In oxygen
Methane	650°–750° ...	556°–700°

The explanation of such behaviour is probably to be sought in the known complexity of the combustion, and the marked tendency for appreciable and fairly rapid interaction between the inflammable gas and oxygen before the actual ignition-point is reached. If, by any means, such preliminary interaction could either be entirely suppressed, or if, on the other hand, it be very rapid in character, the observed "ignition range" would be narrowed, as is actually the case with ethylene (542° to 547° in air, and 500° to 519° in oxygen).

There are two other means by which an explosive mixture may be ignited. One is by adiabatic compression, and the other, and most commonly employed of all, is by the passage of an electric spark. The adiabatic compression of an explosive mixture was originally suggested by Nernst as a means of determining its ignition-point, provided (1) that ignition is not produced locally, while the main temperature of the gas is still far below the true ignition temperature; (2) that the piston of the apparatus does not move appreciably after the gas has been raised to its ignition-point. At the time of my 1910 report, Falk, in America, had applied the method in the case of hydrogen and oxygen mixtures, with results which, in the light of more recent work, would appear to have been misleading or erroneously interpreted. Thus, for instance, he found that of all the mixtures of hydrogen and oxygen, the equimolecular H_2+O_2 mixture has the lowest ignition temperature (514°), from which he concluded that the gases react initially to produce hydrogen peroxide rather than steam. Such a conclusion, which I believe to be erroneous, naturally directed attention to the experimental method involved.

The subject was promptly taken up here, in Manchester, by H. B. Dixon and his co-workers,[4] with the result that much new light has been thrown on the phenomena accompanying ignition. The ratio of the ignition temperature to the initial temperature of the mixture before compression, both expressed in degrees absolute (T_2/T_1), may be calculated from the compression ratio (V_1/V_2) by means of the well-known formula for adiabatic compression :

$$\frac{T_2}{T_1}=\left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

where γ=the ratio of the specific heats at constant pressure and volume, respectively, of the mixture compressed, and which for a mixture of diatomic gases, such as hydrogen and oxygen, is usually taken as 1·40.

Dixon's recent photographic analysis of the appearance of flame when mixtures of carbon bisulphide and oxygen (CS_2+3O_2) are adiabetically compressed, have proved that the flame, starting from a point or layer, always takes an appreciable time to spread through the mixture, and that unless special precautions are taken to arrest the piston at the moment of its attainment of the ignition condition, it may be driven in much further than the minimum distance for ignition.

The real ignition-point, as above defined, is not necessarily synchronous with the actual appearance of the flame. There may be, and usually is, an appreciable "pre-flame" period. Only in the fastest burning mixtures is this period negligible; hence the necessity of artificially stopping the movement of the piston at the beginning of the period—a precaution which Falk seems to have neglected.

According to Dixon and Croft's recent determination by this method of the ignition-points of mixtures containing electrolytic gas, whereas successive additions of hydrogen or nitrogen progressively raise the ignition temperature of the undiluted gas by regular increments, as would be supposed, successive additions of oxygen, on the other hand, lower it, as a glance at the following table will show :—

Ignition Points of Mixtures Containing Electrolytic Gas by Adiabatic Compression.

(H. B. Dixon and J. M. Crofts, 1914.)

Electrolytic Gas, $2H_2+O_2$=526°

$+x\ H_2$		$+x\ N_2$		$+x\ O_2$
x=1 ... 554°	...	x=1 ... 537°	...	x= 1 ... 511°
x=2 ... 561°	...	x=2 ... 549°	...	x= 7 ... 478°
x=4 ... 602°	...	x=4 ... 571°	...	x=15 ... 472°
x=8 ... 676°	...	x=8 ... 615°		
(526+18 x)°	...	(526+11 x)°		

The observed raising effects of successive dilutions with hydrogen and nitrogen call for no comment, save that the relatively greater effect of hydrogen as compared with nitrogen may be attributed to its greater thermal conductivity; but the lowering effect of oxygen is indeed puzzling, and its meaning can only be conjectured. Dixon and Crofts have suggested that it may be due either to the formation of some active polymeride of oxygen under the experimental conditions, which seems to me doubtful, or that the concentration of oxygen in some way or other brings about increased ionisation of the combustible gas. This at once raises the larger question of whether or not ignition is a purely thermal problem, as until recently has generally been supposed

Prof. W. M. Thornton, of Newcastle-upon-Tyne, recently published some very suggestive work on the "Electrical Ignition of Gaseous mixtures,"[5] which, apart from its theoretical interest, has an important bearing on the safety of coal mines where electrical currents are used for signalling and other purposes.

The common belief that any visible spark will ignite a given explosive mixture of gas and air is, of course, quite erroneous; for just as Coward and his co-workers have shown that for a given explosive mixture and sparking arrangement there is a certain limiting pressure of the gaseous mixture below which ignition will not take place, so from Thornton's work it would appear that a definite minimum of circuit energy is required before a given mixture at given pressure can be ignited by a spark. And, moreover, he has stated that the circuit energy required for the spark ignition of a given mixture (say) of methane and air is something like fifty-six times greater with alternating than with continuous current at the same voltage. From this he has argued that the igniting effect cannot be simply thermal, but must be in part at least ionic This conclusion he further supports with the statement that the igniting power of a unidirectional current is proportional to the current in the case of many gaseous mixtures over an important part of their working range of inflammability.

While there is much that is suggestive in Thornton's work, there is also a good deal which seems very difficult to interpret from a chemical viewpoint. I here refer more particularly to his later supposition of "stepped ignition," which is based upon certain observed abrupt increases in the minimum igniting current required with condenser discharge sparks as the proportion of combustible gas in the air mixture examined progressively increases. In other words, it is claimed that continuous alteration of the proportions of gas and air in an explosive mixture is, or may be, accompanied by discontinuous alterations in the spark energy required for ignition. I must confess that, after careful examination of the published curves, I am quite at a loss to give them any chemical interpretation, and to being somewhat sceptical about the supposed "stepped ignition." A repetition and extension of Prof. Thornton's experiments would be most valuable as a means to a better understanding of the conditions of spark ignition.

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[4] H. B. Dixon, L. Bradshaw, and C. Campbell, Trans. Chem. Soc., 1914, pp. 105, 2027 ; H. B. Dixon and J. M. Crofts, *ibid.*, p. 2036.

[5] Proc. Roy. Soc., A, vol. xc., 1914, p. 272 ; vol. xci., 1914, p. 17.

Influence of Electrons upon Combustion.

During the discussion upon my 1910 report, Sir J. J. Thomson reminded us chemists that combustion is concerned, not only with atoms and molecules, but also with electrons moving with very high velocities. They might be a fact of prime importance in such intensive forms of gaseous combustion as are realised in contact with hot or incandescent surfaces, as also in the explosion wave. It is well known, of course, that incandescent surfaces emit enormous streams of electrons travelling with high velocities, and the actions of such surfaces may be due to the formation of layers of electrified gas in which chemical changes proceed with extraordinarily high velocities. Again, the rapidity of combustion in the explosion wave might, he thought, conceivably be due to the molecules in the act of combining sending out electrons with exceedingly high velocities, which precede the explosion wave and prepare the way for it by ionising the gas.

With regard to this interpretation of the action of surfaces, Mr. Harold Hartley carried out a promising series of experiments in my laboratory at Leeds University upon the combination of hydrogen and oxygen in contact with a gold surface, which lend some support to the idea. But they require further extension before it can be considered as finally proved. It is my intention in the near future to resume the systematic investigation of the matter as rapidly as circumstances permit; but the experimental difficulties are formidable, and the mere chemist working by himself may easily be misled. We badly need the active co-operation of physicists in elucidating the supposed *rôle* of electrons in combustion.

Prof. H. B. Dixon and his pupils have, at Sir J. J. Thomson's suggestion, recently tested the idea as applied to the explosion wave, with, however, negative results.[6] It is known, of course, that the motion of the ions can be stopped at once by means of a transverse magnetic field, in which they curl up, and are caused to revolve in small circles; and the question which Prof. Dixon decided to put to the test of experiment was whether the damping of the electronic velocities in a powerful magnetic field would have any appreciable effect either upon the initial phase of an explosion or upon the high velocity of detonation. But though he employed a very intense magnetic field produced by some powerful magnets specially constructed by Sir Ernest Rutherford for the deflection of electrons of high velocity, no appreciable effect was observed upon the character or velocity of the flame with any gas mixture at any stage of the explosion. And inasmuch as the high constant velocity of the explosion wave can be entirely accounted for on the theory of a compression wave liberating the chemical energy as it passes through the gases, there seem as yet to be no experimental grounds for attributing it to the ionising action of electrons.

The Initial Period of "Uniform Movement" or "Inflammation" of Flame through Inflammable Mixtures, and Limits of Inflammability.

Mallard and Le Chatelier, in their classical researches upon the combustion of explosive mixtures, discovered that the propagation of flame, when such a mixture is ignited in a horizontal tube, differs according as whether the ignition occurs near the open or closed end of the tube. In the first case, the flame proceeded for some distance down the tube at a practically uniform and fairly slow velocity, corresponding to the true rate of propagation "by conduction." This period of uniform movement is succeeded by an irregular oscillatory period, in which the flame swings backwards and forwards with increasing amplitudes, finally either dying out altogether or else giving rise to detonation. With certain oxygen mixtures, the initial period of uniform slow velocity was shorter, and appeared to be abruptly succeeded by detonation without the intervention of any oscillatory period. When, however, such mixtures were ignited near the closed end of a horizontal tube, the forward movement of the flame was continuously accelerated from the beginning, under the influence of reflected compression waves, until detonation was set up. Such, in general, was the sequence of the phenomena that were observed by these distinguished French investigators.

They proceeded to determine experimentally the velocities of the uniform slow movement of the flame in the case of a number of air and combustible gas mixtures, and plotting their results (in cms. per sec.) as ordinates against percentages of inflammable gas as abscissæ, they obtained "curves" which were in each case formed of two inclined straight lines converging upwards to a point which represented the composition and flame velocity of the most explosive mixture. And they concluded that the points at which the downward production of the two lines met the zero velocity line would define the upper and lower limits of inflammability for the particular series of gas-air mixtures. Thus the curve they obtain for methane-air mixtures showed a maximum velocity of 61 cms. per second for a mixture containing about 12·2 per cent. of methane, with lower and upper limits corresponding to 5·6 and 16·7 per cent. of methane respectively.

An exact knowledge of the velocities of flame propagation during this initial period of uniform slow movement, as well as of the limits of inflammability for mixtures of various combustible gases and air, is very important from a practical point of view. Makers of apparatus for burning explosive mixtures of gas and air want to know the speed of flame propagation through such mixtures, not only at ordinary temperatures and pressures, but also when the mixtures are heated and used at higher pressures. Also, it would be important to know whether or not, in the case of a complex mixture of various combustible gases and air, when complete composition can be determined by analysis (as, for example, coal gas and air), the velocity of flame propagation can be calculated from the known velocities for its single components. Unfortunately, although more than thirty years have elapsed since Mallard and Le Chatelier's work was published, the necessary data are still wanting to answer such questions; and anyone who will systematically tackle the problem and carefully work it out in detail will be doing a real service to the gas-using industry.

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[6] Proc. Roy. Soc., 1914, Section A, vol. xc., p. 506.

An accurate knowledge of the behaviour of methane-air mixtures under known variations of conditions is of prime importance from the point of view of the safety of coal mines, and it is rightly occupying the attention of my friend and former collaborator, Dr. R. V. Wheeler, at the Home Office Experimental Station at Eskmeals. From papers which he has already published, as well as from some unpublished results which he has very kindly permitted me to refer to in this address, it is now possible to correct certain errors in Mallard and Le Chatelier's results, and to arrive at a clear view of the phenomena as a whole.

In the first place, it would appear that the initial "uniform movement" of flame in a gaseous explosion, or, in other words, propagation of the flame from layer to layer by conduction only (as defined by Le Chatelier) is a limited phenomenon, and is only obtained in tubes of somewhat small diameter—wide enough, however, to prevent appreciable cooling of the flame, but narrow enough to suppress the influence of convection currents. Moreover, ignition must be either at or within one or two centimetres of the end of the tube; otherwise—particularly with the more rapidly moving flames—vibrations may be set up right from the beginning.

While all methane-air mixtures develop an initial uniform slow flame-movement period when ignited at, or near, the open end of a horizontal tube, both its linear duration as well as the flame velocity are not, according to private information which Dr. Wheeler has sent me, independent of the dimensions of the tube. The speed of flame increases with the diameter of the tube; and the linear duration of the uniform period increases with both the diameter and length of the tube up to a certain maximum, after which increased length probably makes no appreciable difference. Also, for the same tube, it varies with the proportion of methane in the explosive mixture—being greater as the speed of the flame diminishes, until with the two "limiting" explosive mixtures it appears to last almost indefinitely.

Dr. Wheeler's recent re-determination of the velocities of the flame movement during this initial uniform period for mixtures of methane and air in varying proportions within the limits of inflammability, has revealed serious errors in Mallard and Le Chatelier's original results for horizontal tubes of the same diameter as those which Dr. Wheeler has employed. Moreover, Mallard and Le Chatelier's method of determining the composition of the upper and lower limits of inflammability by extrapolation from their curves has been proved to be unwarranted. Dr. Wheeler considers the length of the tubes used by Mallard and Le Chatelier (1 metre only) was insufficient to ensure that the speed measurements of the initial uniform flame-movement period were unaffected by the subsequent "vibratory period." Also, the methane used by them, prepared as it was from sodium acetate, would obviously be impure. According to Wheeler, the limits of inflammability for horizontal propagation of flame in methane-air mixtures, at atmospheric temperature and pressure, correspond to 5·4 and 14·3 per cent. methane contents, respectively.

Messrs. Burgess and Wheeler have recently determined the limits of inflammability of methane when mixed, at atmospheric temperature and pressure, with "atmospheres" of oxygen and nitrogen containing less oxygen than ordinary air. From their results (see below) it would appear that, as the oxygen content of the atmosphere is reduced, the limits of inflammability are narrowed until they coincide when the oxygen content falls below 13·3 per cent., which means that an atmosphere containing 13·3 or less per cent. of oxygen is truly extinctive for a methane flame at ordinary pressures.

Atmosphere		Methane, per cent.	
Oxygen	Nitrogen	Lower limit	Higher limit
20·90	79·10	5·60	14·82
17·00	83·00	5·80	10·55
15·82	84·18	5·83	8·96
14·86	85·14	6·15	8·36
13·90	86·10	6·35	7·26
13·45	86·55	6·50	6·70

Behaviour of Weak Mixtures of Gases and Air.

My review of this part of the subject would be incomplete without a reference to some interesting observations which have been made by Dr. H. F. Coward and co-workers at the Manchester School of Technology, upon the behaviour of weak mixtures of various inflammable gases and air, at, or just below, the lower limit of inflammability in each case.[7] Their principal experiments were carried out in a rectangular box of 30 cm. square section and 1·8 metres length, with two opposite sides of wood, and the other two of plate glass. The box was placed in an upright position, the bottom being water-sealed and the top closed, with a suitable igniting device placed near the bottom. They have shown that caps or vortex rings of flame may be projected for some distance upwards from the source of ignition—sometimes apparently for an indefinite distance—without igniting the whole of the combustible mixture. In such mixtures there may be an indefinite upward slow propagation of flame, together with incompleteness of combustion, much of the combustible mixture remaining unburnt, and the question very naturally arises as to how the term "inflammability" should be scientifically defined. Dr. Coward has argued, with some force, that a gaseous mixture should not be termed "inflammable" at a given temperature and pressure, unless it will propagate flame indefinitely—the unburnt portion being maintained at that temperature and pressure. Inflammability thus defined would be a function of the temperature, pressure, and composition of a particular mixture only, and would be independent of the shape and size of the containing vessel; and, provided that it is kept in mind that for each particular mixture at a given temperature and pressure a certain minimum igniting energy and intensity is requisite, I am inclined to agree with the definiton. Also, there is a possibility that in a mixture just at, or very near, one or other of the limits of inflammability, flame may be propagated upwards, but not downwards.

From his experiments, Dr. Coward has assigned the following as the lower limits of inflammability of hydrogen, methane, and carbon monoxide respectively, in air at atmospheric temperature and pressure:—

	Per cent.
Hydrogen	4·1
Methane	5·3[8]
Carbon monoxide	12·6

Recent Investigation upon the Combustion of Hydrocarbons and the Relative Affinities of Methane, Hydrogen, and Carbon Monoxide respectively for Oxygen in Flames.

(This part of the address, which was read as a separate paper, reviewed the principal results of an investigation by Prof. Bone and collaborators on

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[7] Trans. Chem. Soc., 1914, vol. cv., p. 1859.

[8] Too much stress need not be laid upon the difference between this number and the 5·6 per cent. given by Dr. Wheeler (*loc. cit.*), because Dr. Coward himself admits that the flames of mixtures containing from 5·3 to 5·6 per cent. of methane are very sensitive to shock; while a 5·6 per cent. mixture will always propagate flame indefinitely, even when there is a moderate disturbance. The conditions must be exceedingly tranquil to prevent extinction in the other cases.

"Gaseous Combustion at High Pressures," recently published *in extenso* in Phil. Trans. Roy. Soc., A, vol. ccxv. (1915), pp. 275 to 318.)

Fuel Economy and the Proper Utilisation of Coal.

Leaving now the scientific aspects of flame and combustion, I wish to say a few words as a technologist upon the great national importance of a more adequate scientific control of fuel consumption and the utilisation of coal generally, with special reference to the situation created by this terrible and ruinous European conflict. And my remarks will be addressed in part to my chemical friends and colleagues, who are primarily interested in scientific research and its industrial applications, and in part also to the commercial and manufacturing community which is chiefly interested in the financial results of such scientific activity.

Notwithstanding the fact that we are raising annually in the United Kingdom—according to the official estimate for 1913—287 million tons of coal, of which 189 million tons (or, say, 4 tons per head of the population) were consumed at home, more or less wastefully, it is indeed surprising how little has been done, or is being done, by the scientific community to impress upon the Government and the public generally the importance of establishing some systematic control or investigation of fuel consumptions in all large industrial areas. Deputations have waited upon the Government about the question of reviving our languishing coal-tar colour industry; so that in future we may be independent of Germany for the supply of the 2,000,000*l.* of dye-stuffs required by our textile industries; and already a State-aided organisation, with an advisory scientific committee, has sprung into existence to achieve this desirable result. But no organised body of men of science, so far as I know, has ever thought it important, or worth while, to take an active interest in the vastly greater subject of fuel economy and the proper utilisation of coal, upon which the dyeing industry depends for its raw material.

It is unnecessary for me to remind you that the contending armies in this Armageddon of the nations depend upon certain distillation products of coal for their supplies of high explosives; and there is little doubt in my mind but that Germany's violation of the neutrality of Belgium, and her subsequent seizure of that country and of a large tract of northern France, had more than a purely political or strategic significance. She, doubtless, wanted also to seize for herself (and at the same time to deprive her enemies of) coalfields lying just beyond her own borders, which are capable of furnishing abundant supplies of coal admirably adapted for yielding the raw materials for the manufacture of high explosives. A country in which all metallurgical coke has for years past been manufactured under chemical supervision in bye-product coking-ovens, with recovery of ammonia, tar, and benzol, and in which the wasteful beehive coking-ovens have long ago ceased to exist, was scarcely likely to overlook the military importance of the Belgian coalfield with its many bye-product coking-plants. And, moreover, but for German commercial acumen and enterprise, during many years past, our own bye-product industry would not have attained even to its present respectable dimensions. Certainly it owes very little to the interest or attention of British chemists, most of whom are, unfortunately, but little aware of its circumstances and conditions, and seem to care even less for its particular problems. And yet, in proportion to the capital outlaid upon it, it is one of the most profitable of all our chemical industries, coal-tar colours not excepted.

Fuel economy, and the proper utilisation of coal, whether in connection with manufacturing operations or domestic heating, will become one of the most important national questions during the trying years that will follow hard upon this war, because of all directions in which national economy can be most healthfully and advantageously exercised, this is perhaps the most obvious and prolific. For it is tolerably certain that, with an efficient and systematic public supervision of fuel consumption, we ought to be able, even with existing appliances, to save many millions of pounds of our annual coal bill, and with improved appliances still more millions—a saving which would in the long run redeem a considerable amount of the war loan which has been much more easily raised than it will be repaid.

Now, I fear that not only are chemists for the most part lamentably ignorant of the nature of coal, and of modern fuel technology, but they have been for many years past so indifferent about such questions that they have been content to leave them almost entirely to engineers, who, as a body, are notoriously deficient in chemical sense and experience. The engineer has, indeed, not usurped the place of the chemist, but has had to do his best to fill the position long since abdicated by the chemist.

This, indeed, seems strange when we remember that the foundations of modern chemistry were deeply laid by investigators who were, above all things, "fire-worshippers." But, judging from most chemical text-books, nearly all that the modern student of chemistry is taught in our academies about combustion was known to Lavoisier; and I question whether in the majority of our university laboratories any investigation on coal or combustion is ever undertaken. And yet the subject is full of most fascinating and fundamental theoretical problems—for the most part unsolved—and the nation consumes every week as much coal as could be exchanged for the whole quantity of aniline dyes used by its textile industries in a year.

Moreover, such advances as have been made during recent years—and they are by no means inconsiderable—have nearly all been in the direction of the wider applications of gaseous fuels. Yet in how many of our university laboratories is even gas analysis taught, or how many of our schools of chemistry provide systematic courses in the chemistry and manipulation of gases, without which no professional training of industrial chemists, however much "research work" it may include, ought to be considered satisfactory? It is my opinion that this important branch of our chemical craft and science has not, for many years past, been accorded its proper place and share of attention in the ordinary curriculum of the majority of our academic institutions.

Of the 189 million tons of coal consumed in the United Kingdom in the year 1913, about 40 million tons, or, say, approximately one-fifth of the whole, were carbonised either in gas works, primarily for the manufacture of towns' gas, or in coke-ovens for the manufacture of metallurgical coke—in practically equal proportions. Two-thirds of the latter was carbonised in bye-product recovery plants; the remainder in the old wasteful beehive ovens. So that, roughly speaking, we have—

Total coal carbonised=40 million tons

In gas-works		In bye-product coke ovens		In beehive coke ovens
20	...	13·5	...	6·5

At present there are 8297 bye-product coke-ovens built in this country, of which 6678 are fitted with benzol recovery arrangements, capable of producing something like 10 million tons of coke per annum.

The yields of the various bye-products obtainable on such coke-oven installations naturally vary with the locality and character of the coal seam; but they probably average somewhat as follows—expressed as percentages on dry coal carbonised:—

District		Ammonium sulphate	Tar.	Benzol and toluol as finished products
Durham	...	0·9 to 1·45	2·5 to 4·5	0·6 to 1·0
Yorkshire	...	1·3 to 1·5	3·5 to 5·0	0·9 to 1·1
Derbyshire	...	1·3 to 1·6	3·5 to 5·0	0·9 to 1·1
Scotland	...	1·4 to 1·6	3·5 to 5·0	0·9 to 1·1
South Wales	...	0·9 to 1·1	2·0 to 3·5	0·6 to 0·75

Or, to put the matter a little differently, each ton of dry coal carbonised yields from 20 to 35 lb. of ammonium sulphate, from 56 to 112 lb. of tar, and from 2 to 3½ gallons of crude benzol, etc.—according to the locality. About 65 to 70 per cent. of the crude benzol is obtained as finished products—benzene, toluene, solvent and heavy naphthas.

How rapid has been the development of the bye-product coking industry in this country during recent years may be judged from the following official returns of the quantities of ammonium sulphate annually made by such plants, as compared with the corresponding quantities produced in gas-works.

	Tons of ammonium sulphate produced in	
Year	Bye-product coke-oven plants	Gas-works
1903	17,435	149,489
1908	64,227	165,218
1913	133,816	182,180

In the natural course of events, the final disappearance of the wasteful beehive coking-ovens from this country is now only a matter of a few years; but I venture to suggest that public interest would justify the Government fixing, by law, a reasonable time-limit beyond which no beehive coke-oven would be allowed to remain in operation, except by express sanction of the State, and then only on special circumstances being proved.

There is also much need of a better and more systematic chemical control, in the public interest, of bye-product coking plants. At present, in far too many cases, the chemists employed in coke-oven laboratories are men who have practically no chemical training other than that obtained in evening classes. And, with few exceptions, the chemist, however competent he may be, is entirely subordinated to the directing engineer, and regarded as a mere routine analyst. I can say, from personal knowledge, that plants which are managed and controlled by experienced chemists of broad training, combined with force of character, yield much better results than those which are controlled by men without such qualifications.

And even in this crisis when so much depends on plants working, not only at their maximum output capacities, but also, chemically speaking, under conditions calculated to ensure the highest yields of benzol and toluol, with a proper selection of coal, I doubt whether the measures which have been taken to advise and supervise the coke-oven industry are really adequate from the point of view of chemical control. I do know, for instance, that the experience and resources of the majority of our university departments of applied chemistry which specialise on fuel technology and cognate matters have not been as fully utilised as they might have been in this connection. I cannot for one moment imagine a similar state of things being permitted in Germany, where we may be sure that nothing is being left undone in the way of fully utilising all the available expert chemical and engineering knowledge which can be brought to bear on this important aspect of war munitions; and I venture to say that, whatever may be the case in this country, in Germany at least the staff and resources of no publicly maintained department of fuel technology will not be fully employed on war problems.

The coal-gas industry, which deals with some twenty million tons of coal per annum, has, especially within recent years, shown a growing appreciation of the aid of chemical science, in regard not only to the actual manufacture, but also to the domestic and industrial uses of coal gas. The endowment by the industry, in 1910, of a special chair at the Leeds University, in memory of the late Sir George Livesey (of which I had the honour and pleasure of being the first occupant), was a sure sign of the faith of its leaders in the value of scientific research into its special problems; and, from personal knowledge and intercourse with gas engineers, I can assure my chemical colleagues that any serious interest taken by scientific chemists in these problems, or in training men to tackle them, will be welcomed by the industry, no matter from what quarter such help or interest may come. For although the carbonisation of coal in gasworks is efficiently carried out, no one in the industry supposes that finality has been reached, or that existing methods and conditions cannot be improved under better chemical control.

And, moreover, the gas industry has just recently given a striking example of the public benefit which may accrue from the whole-hearted co-operation of the chemist and engineer in the new nickel-catalytic process for the removal of carbon bisulphide from coal gas, which has been worked out, and brought to a successful issue, by the combined skill and efforts of Mr. Charles Carpenter, Mr. W. Doig Gibb, and Mr. E. V. Evans, of the South Metropolitan Gas Company. They have shown that the sulphur content (as CS_2) of London coal gas can be reduced on a large scale, in regular day-to-day working, from nearly 40 to about 8 grains per 100 cubic ft., without in any way deteriorating the quality of the gas, at a cost (including interest and depreciation) of 0·299*d*. per 1000 cubic ft. Such a striking success was, as Mr. Carpenter acknowledges, only achieved "because of the unrestricted and unreserved collaboration of the chemist and the engineer." Incidentally, the gas industry is to be congratulated on this tacit abandonment of the old contention that coal gas was either none the worse for the presence in it of a certain amount of sulphur compound, or (alternatively), if worse, that a minute amount of sulphur dioxide in the atmosphere of a living room is so rapidly absorbed by the ceiling that its harmful effects are nullified.

As the outcome largely of the work of the Joint Committee appointed in 1907 by the Institution of Gas Engineers and the University of Leeds (of which I was a member) to investigate gas-fire problems, the manufacturers of these appliances have paid much more attention than formerly to the scientific aspects of construction, so far as to ensure the best combination of radiant and ventilating effects, and nearly all the larger firms have now their scientific staffs busily employed in making further advances. Prominent among the pioneers in scientific gas-fire construction has been Mr. H. James Yates, who will to-morrow enlighten you as to some of the most recent improvements. I can, however, from personal knowledge testify to the enterprise shown by most of the leading manufacturers, and that their combined efforts have resulted in a very efficient and perfectly hygienic domestic gas-fire. A committee appointed by the Institution of Gas Engineers, upon which scientific men are largely represented, is now considering the adoption of a standard method of testing the radiant efficiencies of gas-fires. Thus no one can say that the gas industry is not making every effort to put its affairs upon a thoroughly scientific basis.

Passing on to the metallurgical and allied industries (who, of course, are large consumers of fuel), there is much here to be done in improving the construction and operation of furnaces in order to check the waste of fuel. But of these details there is no time to treat; and one instance of the possibilities of very large economies as the result of scientific control must suffice.

It is perhaps common knowledge that the most economical arrangement of plant for the manufacture of iron and steel is one in which bye-product coke-ovens, blast-furnaces, steel furnaces, and rolling mills are brought together on one site and under one organising direction, so that the surplus gases from the coke-ovens and blast-furnaces may be utilised to the fullest extent. My relative, Mr. T. C. Hutchinson, of the Skinningrove Iron Company, who has devoted many years of anxious thought and practical study to this important problem, ventured some few years ago to predict that—with the most approved type and arrangement of plant, working under strict scientific control by competent chemists—it would soon be possible to make finished steel rails or girders from Cleveland ironstone with no further consumption of coal than is charged into the bye-product coke-ovens for the production of the coke required for the blast-furnace, and all subsequent experience at Skinningrove has fully demonstrated that his prophecy can be fulfilled in everyday practice. Of course, it means a constant watchful control by a well-paid and competent scientific staff under efficient leadership, and in Mr. E. Bury—an old Owens College student, trained in an atmosphere of "gas and combustion"—we have found the very man for the work.

It is perhaps unnecessary, even had time permitted, for me to multiply instances of possible economies in other important directions—such, for instance, as power production and the heating of domestic apartments. There is probably no direction in which equally good results would not accrue with proper scientific application and control as those already cited as having been reached in the direction of carbonisation, or in the iron and steel industry. To-morrow we are to discuss the important subject of smoke prevention, in which many Manchester public men are showing an active interest, so that there will be some further opportunity of referring to the matter.

But may I, in conclusion, appeal in all seriousness to chemists and scientific men generally to take up this important matter effectively as a public duty at this crisis in the country's affairs? I would suggest that the Government be memorialised with a view to the establishment of a central organisation for the supervision of fuel consumption and the utilisation of coal somewhat on the lines of the existing alkali works inspection, which has been so beneficial to chemical industry. And in connection with such an organisation there might be undertaken a much needed systematic chemical survey of British coalfields, as well as experimental trial of new inventions for fuel economies. There would certainly be no lack of important work for such a properly organised department of the State, and there can be no doubt at all that the results of its activities would be, not only a very large direct saving in our colossal annual coal bill, but also a purer atmosphere and healthier conditions generally in all our large industrial areas.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

CAMBRIDGE.—In his valedictory address to the Senate, the retiring Vice-Chancellor, Dr. M. R. James, the provost of King's College, stated that the University has shrunk to less than one-third of its former numbers; no fewer than 10,000 Cambridge men have entered the military and naval services. The Rev. T. C. Fitzpatrick, president of Queens' College, was elected Vice-Chancellor for the ensuing year. The Quick professorship of biology is vacant, as the period of three years for which Dr. G. H. F. Nuttall was appointed has now ended.

ALTHOUGH much of the best glass used in England is of English manufacture, large quantities of glass, principally of the cheaper types, have been for some years imported. Cheaper labour, cheaper transport, and the scarcity of technically trained managers and chemists, together with the prevalence of "rule-of-thumb" methods, have been the determining factors. The manufacture of fine glass requires a peculiar combination of engineering, physical, and chemical knowledge and training, and the chemical knowledge is not usually obtainable in university or technical college courses, because of the specialised nature of the subjects and the difficulties which arise in translating laboratory experiments into practice on a manufacturing scale. To meet these difficulties, the University of Sheffield has established a department of glass manufacture and technology, and has instituted special technological courses. A syllabus of special lectures and laboratory work has been issued with details of a projected full-time three years' course. The announcement indicates the variety of scientific and technical work which is essential to a good training in glass manufacture, and includes, *e.g.*, the chemistry of the materials, the glasses and pots, the fuel used, the furnaces, the temperatures at which they work, variations in the methods of melting, chemical actions in the process of melting, methods of working the glass, such as rolling, pressing, and blowing, grinding and cutting, and the machinery and appliances incidental to all these operations. The success of these courses will necessarily depend on the co-ordination of the lectures and the laboratory practice with larger scale experimental work; but the University of Sheffield, with its experience of similar problems in the metallurgical department, should be well qualified to deal with these difficult problems. Their successful solution should be of material assistance to a very important and growing branch of British industry which it is particularly essential to encourage as much as possible at the present time.

THE third war programme in connection with the Chadwick Public Lectures dealing with the last quarter of the present year has now been published. Prof. D. Noel Paton is giving a course of three lectures on "Food in War Time" at the Hampstead Central Library, Finchley Road, London, N.W. The first lecture was given on Monday last, and the others will be given on the two succeeding Mondays, at 8.15 p.m. Dr. R. O. Moon, physician to the Serbian Isolation Hospital at Skoplje (Uskub), will lecture on "Typhus in Serbia," at the Royal Society of Medicine, 1 Wimpole Street, Cavendish Square, London, W., at 5.15 p.m. on October 20 and 29, and on November 3. On November 10, at 8.15 p.m., Mr. A. Saxon Snell will lecture on "Emergency Military Hospital Construction" at the Royal Institute of British Architects, Conduit Street, London, W. On November 17, at 8.15 p.m. Mr. W. E. Riley will lecture on "Some Con-